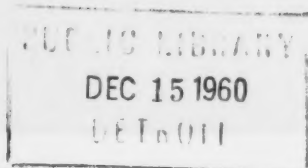


NATIONAL BUREAU OF STANDARDS

# Technical News

BULLETIN



VOLUME 44

NOVEMBER 1960

NUMBER 11



SUPERSONIC  
COMBUSTION  
STUDIES



U.S. DEPARTMENT OF COMMERCE

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NATIONAL BUREAU OF STANDARDS

# Technical News

## BULLETIN

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COVER: Schlieren photograph of a spherical missile moving at Mach 4.90 through a combustible gas. Large-amplitude oscillations (in the megacycle frequency range) visible behind the sphere are generated by an intermittent combustion process occurring at the front of the sphere and its shock wave.

# A Technique for Studying Supersonic Combustion *In the Vicinity of a Hypersonic Missile*

A TECHNIQUE for securing information on the combustion process at supersonic speeds has been developed by the Bureau with the support of the Navy Bureau of Weapons and the Air Force Office of Scientific Research. The technique involves firing a missile at hypersonic velocities through a combustible gas. High-speed schlieren photography is used to obtain data concerning shape and detachment distance of the shock wave, gas density, and other effects. These data are evaluated to derive information on the combustion process in the vicinity of the missile.

This experimental method, devised by F. W. Ruegg of the combustion controls group, permits precisely controlled variation of such parameters as pressure, temperature, fuel, and speed over a wide range under realistic conditions and at very little cost. It can be employed to examine in advance some of the problems of stabilizing detonation waves on a stationary object in a moving combustible mixture. If the wave can be established at the front of the missile, the drag will be substantially reduced. Results of studies using this method might be applied to the generation of thrust by burning at supersonic velocities either on the exterior of a missile or within it. Also, the method should contribute to the design of flame holders for supersonic combustion.

During the investigation, laminar combustion in a supersonic stream was observed for what is believed to be the first time. An unusual occurrence was that of large-amplitude oscillations in the megacycle frequency range produced by the combustion process at the front of the missile.

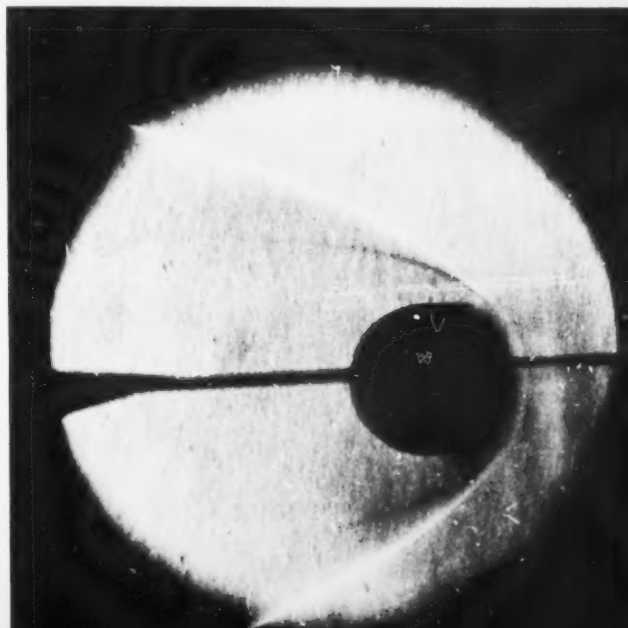
The study of the combustion process in standing detonation waves and in supersonic streams is of great practical importance in the field of propulsion of hypersonic missiles and planes. Extensive information obtained in tube experiments is available concerning moving, plane detonation waves, but this body of data cannot with any assurance be simply transposed to the converse situation of a moving gas and a stationary oblique wave on a solid object. Furthermore, the object itself may exert unforeseen influence.

Some information has recently been obtained on the action of both normal and oblique shocks in inducing combustion in closed ducts<sup>1</sup> and in

free jets.<sup>2</sup> The results are somewhat ambiguous, however, because of fuel and air mixing problems that exist in streams at high speed and temperature. Also, the range of experimental conditions was limited by difficulties encountered in attempting to produce high-speed streams at high stagnation temperature and pressure.

The technique developed at the Bureau overcomes these obstacles by creating conditions such that a shock wave is established ahead of a high-speed missile, and then determining the conditions required to induce combustion and observing the effects of the missile on the combustion process. The stagnation temperatures attained are realistic, and the results are not affected by the method of mixing air and fuel or by turbulence. The experiment can easily be modified to determine the effects of the temperature and pressure history of the combustible gas on the combustion in the shock wave.

The Bureau's experiments were performed at Mach numbers from 4.2 to 6.5 in a mixture of hydrogen (30 percent by volume) in air. Combustion was initiated by means of compression and heating within the shock wave standing on the missile. Characteristics of the combustion process depended strongly on the Mach number and on the state of the gas ahead of the wave.



Schlieren photograph of test missile moving at Mach 5.53, showing laminar combustion in a supersonic stream. This is believed to be the first observation of this phenomenon (absolute pressure, 1/4 atm).

The experimental apparatus comprises three essential parts: A gun and a range that contains the missile and the test gas, an electronic time-delay-ratio generator that computes the time to fire a high-voltage flash lamp, and an optical system for schlieren photography.

In the experiments performed up to the present, 0.785-in.-diam nylon spheres were used as missiles. The sphere is mounted in a 20-mm case containing a fast-burning gun powder and fired from a .60-caliber, 6-ft-long test barrel through a blast chamber and the test section to a heavy metal target and trap. Two phototubes are located upstream of the test gas, which is isolated from the remainder of the system by two plastic diaphragms.

Elapsed time of flight of the missile between the two phototubes is measured by an electronic timer that counts the number of pulses from an oscillator operating at a frequency of 1 Mc. Signals from the phototubes enter the time-delay-ratio generator, which computes the time of arrival of the missile at the photographic station and triggers the high-voltage flash lamp at that time. A second electronic timer measures the time between the missile's arrival at the second phototube and the time at which the lamp is flashed. Two speed measurements are thus available for calculating the deceleration of the missile in the test section.

The schlieren photographs recorded by the optical system provided an opportunity to observe several unusual occurrences. When the missile was traveling at a velocity near Mach 4, separate shock and laminar combustion waves were observed at the front of the sphere. At about Mach 5, combustion was intermittent. At higher speeds, the wave shown at the front of the missile was considered to be a strong detonation wave which separated into a shock and a laminar combustion wave. At pressures of  $\frac{1}{4}$  and  $\frac{1}{2}$  atm, combustion caused the stagnation temperature to rise in the detonation wave by an estimated 700 and 1,000 °C, respectively, above the temperature due to the motion of the missile.

The frequency of the intermittent combustion at the front of the spherical missile was estimated as 0.8 Mc. Although extremely high, this frequency is not unreasonable when one considers the ignition delay time observed in experiments where combustion is steady.

The Bureau is continuing to use this experimental technique in the study of supersonic combustion.

<sup>1</sup> Studies in connection with stabilized gaseous detonation waves, by J. A. Nicholls, E. K. Dabora, and R. L. Gealer, 7th Symp. on Combustion, 1958 (Butterworth's Scientific Publications, London, England, 1959).

<sup>2</sup> Exploratory studies of combustion in supersonic flow, by Robert A. Gross, AFOSR TN 59, 587, ASTIA AD 216769 (June 1959).

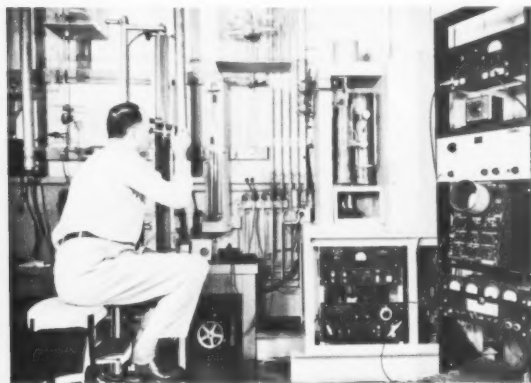
## Redetermination of the National Carbon-14 Standard

THE VALUE of the national sodium carbonate- $C^{14}$  standard has been redetermined with increased accuracy at the Bureau.<sup>1</sup> The revised value of the standard is  $1,250 \pm 1.5$  percent disinte-

grations per second per gram of solution, as compared with a value of  $1,280 \pm 10$  percent dps/ml of solution obtained in 1949. The redetermination was made by W. B. Mann, H. H. Seliger, W. F. Marlow, and R. W. Medlock of the Bureau's radioactivity laboratory.

Developments in low-level counting techniques are making possible their application to research in chemical, biochemical, and industrial processes having rigid requirements that cannot be met by ordinary laboratory procedure. Recently developed equipment will be capable of more precise measurement only to the extent of the accuracy of its calibration. The redetermined value of carbon-14 radioactivity is useful in these areas, as well as in such extensive fields as metabolism studies based on tracer techniques and geological and archeological dating.

Apparatus used in redetermination of the national sodium carbonate- $C^{14}$  standard. W. B. Mann reads pressures in calibrated volumes of the gas-handling system.



The Bureau in 1949 issued the first national carbon-14 standards in the form of sodium carbonate- $C^{14}$ . These standards were measured by counting the carbon in the form of carbon dioxide in length-compensated internal gas counters in the Geiger region. The stated uncertainty in these standards was  $\pm 10$  percent, reflecting possible wall effects (of the order of 2 percent) and a lack of agreement (about 15 percent) among results from the Bureau and two other laboratories participating in comparative measurements. Discrepancies as large as 15 percent were subsequently reported between results obtained in the proportional and the Geiger regions.

The objects of the present investigation of the carbon-14 standard disintegration rate were to examine and resolve these discrepancies, and to determine the conditions under which carbon-14-labeled carbon dioxide could be counted with

nearly 100 percent efficiency in the same counters in both the proportional and the Geiger regions. These objectives were accomplished within the limits of experimental error, and the uncertainty in the value of the NBS sodium carbonate- $C^{14}$  standards was reduced by an order of magnitude.

The redetermined sodium carbonate- $C^{14}$  standard sample may be obtained from the Radioactivity Section, National Bureau of Standards, Washington 25, D.C. for \$27.<sup>2</sup>

<sup>1</sup>For further information, see Recalibration of the NBS carbon-14 standard by Geiger-Müller and proportional gas counting by W. B. Mann, H. H. Seliger, W. F. Marlow, and R. W. Medlock, *Rev. Sci. Instr.* **31**, 690 (1960).

<sup>2</sup>A complete listing of standard samples is contained in Standard Materials, NBS Circular 552 (third edition), available from the Superintendent of Documents, U.S. Government Printing Office, Washington 25, D.C. (35 cents).

## A Carbon-14 Standard for Liquid-Scintillation Counters

THE BUREAU has prepared a new carbon-14 standard sample to meet the need created by the increased use of liquid-scintillation counters, particularly in biochemical and medical studies. The solvents most often used in these counters are toluene and xylene; the standard used in their calibration must therefore be soluble in and compatible with these compounds. To fulfill this requirement, W. F. Marlow and R. W. Medlock of the radioactivity laboratory used benzoic acid- $C^{14}$  dissolved in toluene for the new standard.<sup>1</sup>

In the past few years, liquid-scintillation counting systems have become increasingly accurate and reliable, while their cost has greatly decreased. The sample of material to be counted by this method is more easily prepared than for most other methods, and since it is dissolved directly in the solution, the counting efficiency is usually much greater, especially for low-energy radiations of carbon-14.

The sample of benzoic acid- $C^{14}$  in toluene was standardized by quantitative oxidation of the benzoic acid and toluene. The carbon dioxide produced was collected and the level of radioactivity of this carbon dioxide was compared, in an ionization chamber, with the radioactivity of carbon dioxide prepared quantitatively from the national sodium carbonate- $C^{14}$  standard.

Previous work<sup>2</sup> has shown that  $C^{14}O_2$  and  $C^{12}O_2$  may be evolved at different rates during oxidation of organic compounds either by wet combustion

or by burning in an oxygen stream. The possibility of error due to this isotope effect was avoided by burning the sample in a modified Paar oxygen bomb to obtain complete oxidation.

The new carbon-14 standard sample may be obtained from the Radioactivity Section, National Bureau of Standards, Washington 25, D.C. for \$27.<sup>3</sup>

<sup>1</sup>For further information, see A carbon-14 beta-ray standard, benzoic acid- $C^{14}$  in toluene, for liquid-scintillation counters, by W. F. Marlow and R. W. Medlock, *J. Research NBS* **64A**, 143 (1960).

<sup>2</sup>Errors of combustion of compounds for  $C^{14}$  analysis, by W. D. Armstrong, L. Singer, S. H. Zbarsky, and B. Dunshee, *Science* **112**, 531 (1950).

<sup>3</sup>A complete listing of standard samples is contained in Standard Materials, NBS Circular 552 (third edition), which may be obtained by writing to the Superintendent of Documents, U.S. Government Printing Office, Washington 25, D.C. (35 cents).



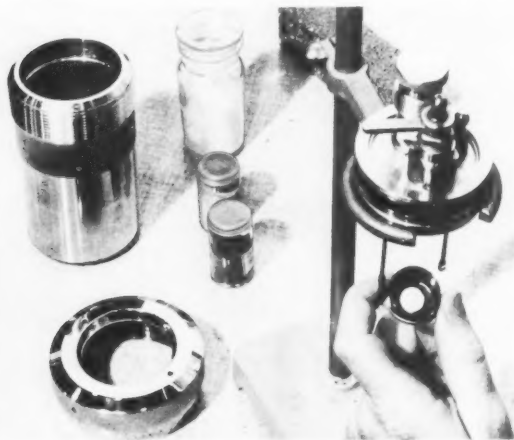
W. F. Marlow (right) and R. W. Medlock fill and seal ampoules with the benzoic acid- $C^{14}$  standard (center flask) for liquid-scintillation counters.



# POTENTIAL HEAT OF MATERIALS IN BUILDING FIRES

A DIFFERENTIAL bomb calorimetric procedure for measuring quantitatively the actual potential heat (in Btu per unit weight, volume or area) of materials in building fires has been developed by the Bureau, and applied to a wide variety of materials. The method, a modification of a recent standard of the French government,<sup>1</sup> resulted from a study conducted by J. J. Loftus, D. Gross, and A. F. Robertson of the Fire Research Section. The findings show that the method provides a useful tool for quantitative evaluation of the potential heat contribution of building elements when subjected to fire.

At present, building codes contain various requirements with respect to the "noncombustible" properties of materials to be used in different portions or types of buildings.<sup>2</sup> Although the extent to which building materials burn and add heat to fires is thus considered important by building code officials, the commonly used noncombustibility test methods usually measure some combination of the flammable, smoldering, and heat release properties of a material. However, the results are usually of a qualitative nature with emphasis varying, depending on the material and test method used. The method studied at the Bureau now appears to provide a procedure for measuring the heat release of materials under standardized conditions and independent of flammability and smoldering properties.



Fuel pan containing sample pellet ready to be placed in oxygen bomb (here disassembled) for measuring potential heat of materials in building fires. Bomb will be assembled and placed in calorimeter. The jars contain other pulverized materials, contents of largest jar being benzoic acid, used as combustion promoter with materials of low combustible content.



Sample of material being pulverized with mortar and pestle as part of procedure for measuring potential heat of materials in building fires. Also shown: Handmill and a file, used to grind certain other building materials into powder, and (on table) various materials studied for potential heat.

Recently, various methods for quantitative measurement of heat release have been considered. The Factory Mutual Association has described a calorimetric furnace to measure heat release rates for 4-ft-square test samples of construction.<sup>3</sup> The French government test method, which was the basis for the method developed by the Bureau, makes use of a differential oxygen bomb calorimetric procedure.

In the Bureau's method, calorimetric measurements are performed on the test material both before and after exposure to a "standardized fire" (2 hr in an oxidizing atmosphere at 750 °C). The difference may be considered the potential heat.

This procedure has been applied to various materials, including metals, and the results appear to be consistent with behavior of these materials in actual fires.

The method has been found to be particularly well suited for measurements on materials of low

combustibility. For such measurements, a combustion promoter whose heat of combustion is accurately known can be added, so that complete burning of small quantities of combustible in an otherwise inert material is assured. In fact, it has been found, by comparison of computed and measured potential heat of mixtures of hydrated plaster and charcoal, that the method is capable of measuring combustible content in amounts as low as 1 or 2 percent.

The method also is designed to yield realistic potential heat values for materials, including some metals, which are completely burned in an oxygen bomb calorimeter, but which contribute only small quantities of heat in actual building fires.

### Test Method

The steps involved in the test method are as follows:

Two samples are removed from the material to be tested. One of these is ground, pelletized, and then burned in a pressurized oxygen bomb calorimeter, yielding a measure of the gross heat of combustion of the material. With materials of low combustible content, an equal weight of calorimetric standard benzoic acid, the combustion promoter, is added prior to pelletizing the specimen for test. This ensures complete burning of the combustible fraction.

A second specimen, of about  $\frac{1}{2}$  by  $\frac{3}{4}$  by 3 in. in size, is fired by exposure to the oxidizing at-



Specimen container and firebrick support being placed in muffle furnace for firing, part of procedure for measuring potential heat of materials in building fires.

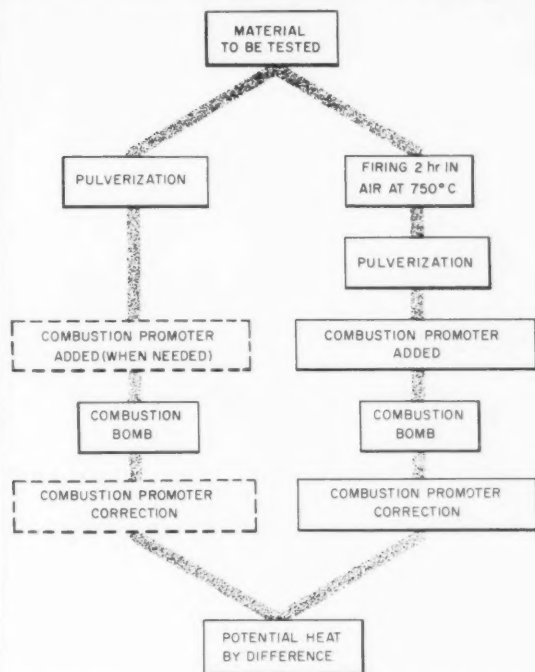
mosphere of a muffle furnace for 2 hr at a temperature of 750 °C. The weight loss of the specimen is noted, and the residue remaining is ground or pulverized. A portion of this resulting powder corresponding to a known weight of the original material is mixed with the benzoic acid promoter, pelletized, and burned in the calorimeter.

Corrections are made for the heat contributed by the benzoic acid, and the difference in heating values of the two specimens is reported as the potential heat.

The selection of the standard fire exposure conditions to which the specimen is subjected in the muffle furnace ensures the complete combustion of the fuel fraction in cinder concrete and the oxidation of carbon resulting from the pyrolysis of wood. The temperature of 750 °C has long been used in combustibility test methods both in the United States and abroad, and is high enough to cause many reactions which occur in building fires. In the case of metals, for example, magnesium ignites under the firing conditions while aluminum melts without becoming inflamed. These are results typical of fire experience.

### Results With Various Materials

Materials studied (table, p. 186) included woods, plastics, metals, insulation materials of various types, concretes, and plasters. Their potential heat values ranged from -290 Btu/lb for gypsum plaster to over 17,000 Btu/lb for polystyrene. Negative potential heat values are indicative of endothermic reactions occurring during the muffle furnace exposure. The negative value



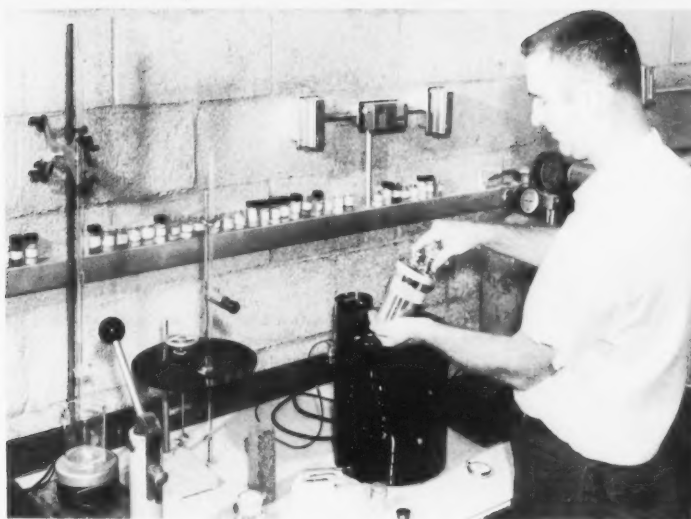
Method developed for measuring potential heat of materials in building fires, shown schematically.

Material	Thick- ness	Density	Potential Heat			
			Weight basis	Volume basis	Unit area basis *	Flame spread index
<b>1. Woods</b>	<i>in.</i>	<i>lb/ft<sup>3</sup></i>	<i>Btu/lb</i>	<i>Btu/ft<sup>3</sup></i>	<i>Btu/ft<sup>2</sup></i>	
a. Douglas fir, untreated	3/4	38.0	8,400	319 × 10 <sup>3</sup>		69
b. Douglas fir (retardant treatment "A")	3/4	37.2	8,290	308		5
c. Douglas fir (retardant treatment "B")	3/4	47.2	7,860	371		3
d. Douglas fir (retardant treatment "C")	3/4	38.8	7,050	274		1
e. Maple, soft, untreated	1	39.5	7,940	314		82
f. Hardboard, untreated	1/4	59.8	8,530	510		150
<b>2. Plastics</b>						
a. Polystyrene, wall tile	0.075	65.4	17,420	1,140		335
b. Rigid, polyvinyl chloride, retardant treated	.147	86.0	9,290	799		10
c. Phenolic laminate	.063	76.4	7,740	592		107
d. Polycarbonate resin	1/4	78.7	13,330	1,050		56
<b>3. Insulation</b>						
a. Glass fiber, semirigid, no vapor barrier	1	3.0	3,040	9.1		
b. Rock wool batting, paper enclosure	3	2.4	1,050	2.5		
c. Roof insulation board	1	10.4	3,380	35.1		61
d. Cork (reconstituted cork sheet)	1/4	14.8	11,110	164		174
e. Cellulose mineral board	2	47.8	2,250	108		1.3
<b>4. Concrete</b>						
a. Cinder aggregate		93.0	3,080	286		0.0
b. Slag aggregate		110.1	80	8.9		
c. Shale aggregate		80.5	10	0.5		
d. Calcareous gravel aggregate		133.1	-250	-33.1		
e. Siliceous gravel aggregate		166.8	-40	-6.7		
<b>5. Cement Board</b>						
a. Asbestos cement board	3/16	117.0	80	9.2		.0
b. Asbestos cement board + 20 mil paint	3/16	159.2	390	62.4		.7
<b>6. Gypsum</b>						
a. CaSO <sub>4</sub> ·2H <sub>2</sub> O, hydrated neat gypsum	0.41	137.9	-290	-31.3		.0
b. Perlite aggregate plaster, 21 percent aggregate	1	53.2	70	4.0		.0
c. Sand aggregate plaster, 68 percent aggregate	1	101.8	-50	-5.4		.0
d. Vermiculite aggregate plaster, 15 percent aggregate	1	51.2	-90	-4.6		.0
e. Gypsum board "A"	3/8	50.5	760	38.4		14.3
f. Gypsum board "A" with paper removed	3/8	46.6	-270	-12.5		.0
g. Gypsum board "A" + alkyd gloss paint	3/8	46.7	880	41.2		8.0
h. Gypsum board "B"	1/2	51.2	650	33.0		7.9
<b>7. Lath</b>						
a. Gypsum A	3/8	55.3	310	17.0		
b. Metal diamond mesh	.025	405	1,230		1,370	0.0
c. Metal diamond mesh, paint removed	.019	401	660		420	.0
<b>8. Metals</b>						
a. Structural steel—unpainted	.060	489	230		190	
b. Magnesium	.128	122	10,800		5,400	
c. Aluminum	.004	165	30		0.8	
d. Brass	.004	534	100		8.9	
e. Copper	.024	556	60		32	
f. Lead	.036	710	280		278	
g. Zinc		415	760		2,390	
<b>9. Miscellaneous</b>						
a. Paint "E" (dried paint film)	.05		3,640			30
b. Asphalt shingles (fire retardant)	1/4	70.7	8,320	588		123
c. Building paper (asphalt impregnated)	.042	42.8	13,620	583		385
d. Building paper (rosin sized)	.018	23.6	7,650	181		192
e. Linoleum tile	1/4	86.0	7,760	667		106
f. Brick, red-face	2 1/4	139.1	20	2.2		0.0
g. Charcoal, coconut			13,870			

\* Based upon total exposed surface area.

NOTE: All weights and percentages refer to original air-dry weight.





**J. J. Loftus places oxygen bomb in calorimeter bucket, in preparation for firing sample pellet of building material. Also shown (on laboratory bench): Calorimeter cover with thermometer and stirrer; pellet press; benzoic acid and combustion promoter in bottle; cinder block specimen before pelletizing; and specimen container in a refractory support.**

for gypsum results from at least partial chemical decomposition of the hydrated gypsum.

Materials such as brick, asbestos-cement board, and some concretes showed very low potential heat, whereas cork, polystyrene, and asphalt-impregnated building paper produced very high values. Expanded metal lath, and gypsum lath and wall board exhibited potential heat values which were low but not zero. Some of the "noncombustible" insulation materials also showed low (but not negligible) potential heat. The potential heat for glass fiber material resulted from the phenolic binder.

The potential heat values for expanded slag, shale, and siliceous aggregates were nearly zero. The potential heat for the concrete incorporating a calcareous aggregate was slightly negative. This latter result would be expected because of the heat absorption required for calcination of the aggregate. However, the cinder aggregate concrete specimens exhibited significantly positive values of potential heat.

The plaster specimens showed low or negative potential heat values which were not as high as those of gypsum wall board. The latter were affected by combustion of the paper facing and of the finish.

Of the metals tested only steel, copper, and brass did not melt at the muffle temperature. However,

with the single exception of magnesium, the oxidation of the metals was not severe, and potential heat should be considered low but not zero.

During the studies performed, only one material, graphite, failed to burn in the bomb, but was consumed in the firing process. Charcoal, on the other hand, which comprises carbon with chemically bonded hydrogen, readily burned in the bomb.

With woods and plastics, the quantity of residue (ash) remaining after firing was so small that it was not necessary to make a calorimetric determination on the residue, and the potential heat was considered equal to the gross heat of combustion.

<sup>1</sup> Sécurité contre l'incendie, classification des matériaux et éléments de construction. Journal Officiel de la République Française. No. 59-23-S (January 1959).

<sup>2</sup> Some of the current and proposed test methods are included in the following:

a. National Board of Fire Underwriters—"National Building Code," 1955 Edition, pages 17-18.

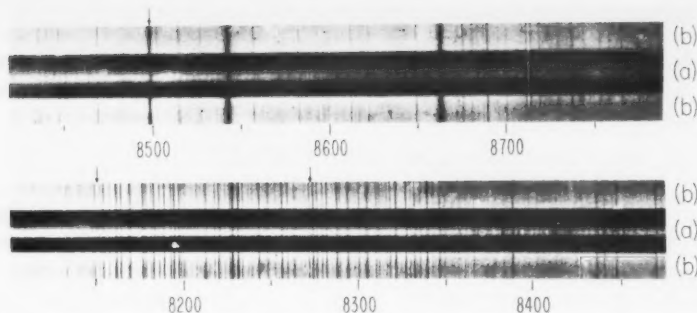
b. National Fire Protection Association Committee on Building Construction—"Standard Types of Building Construction—Definition of Noncombustibility," NFPA No. 220-1946. (National Fire Codes, Vol. III, 1960-61.)

c. American Society for Testing Materials Committee E-5. "Tentative Method of Test for Determining Noncombustibility of Elementary Materials," ASTM E-136-59T, ASTM Standards 1959.

d. British Standards Institution. "Fire Tests on Building Materials and Structures—Combustibility Test of Materials," British Standard 476:53, pages 6-7.

e. N. P. Setchkin and S. H. Ingberg. "Test Criterion for an Incombustible Material," Proc. ASTM V. 45, pages 866-77 (1945).

<sup>3</sup> N. J. Thompson and E. W. Cousins. "The FM Construction Materials Calorimeter," Quarterly of the National Fire Protection Association, V. 52, No. 3, Jan. 1959, pages 186-192.



(a) Spectrum of Jupiter obtained by using high-dispersion gratings and (b) spectrum of Moon. Arrows indicate lines of molecular hydrogen.

# The Spectrum Photographed Up H Ging

**A**N ANALYSIS of spectrograms of the planet Jupiter has recently been completed at the Bureau.<sup>1</sup> For the first time detailed wavelength measurements have been made of the lines in various absorption bands of methane and ammonia. In the infrared region, four lines of the quadrupole rotation-vibration spectrum of the hydrogen molecule were found, confirming the presence of hydrogen in Jupiter's atmosphere. In the violet and ultraviolet regions, a continuous absorption was recorded that closely resembles that of the nitrogen tetroxide molecule. Another investigation is planned using equipment especially appropriate to the study of the far ultraviolet region.

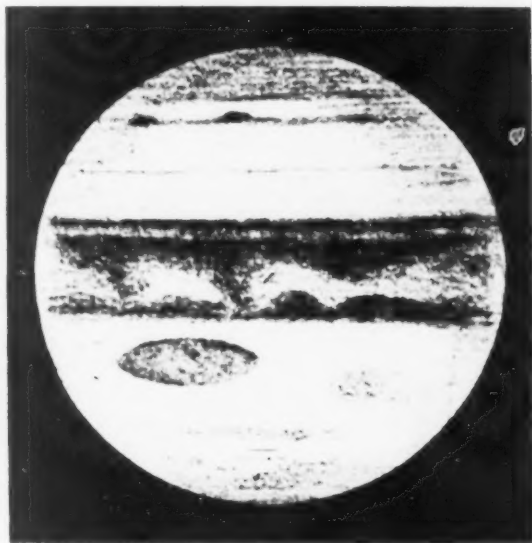
The planet was photographed over the region from 3600 to 8900 Å using concave gratings providing dispersions of 2, 2.5, and 5 Å/mm. The spectrograms were obtained in May 1957 by C. H. Corliss and C. C. Kiess of the Bureau and H. K. Kiess at the U.S. Weather Bureau's Slope Observatory on the side of the Hawaiian volcano Mauna Loa. The observatory is located about 1 mi above the inversion layer of the atmosphere where the surrounding air is relatively free from atmospheric dust and moisture. Another advantage is that the contiguous terrain lacks the ruggedness that produces turbulence in the air. The expedition was under the joint sponsorship of the Bureau and the National Geographic Society. Additional spectrograms were obtained at the Georgetown College Observatory in Washington, D.C. in 1959.

The spectrographic plates were measured and analyzed at NBS. The reference standards of wavelength used in the analysis were lines of both solar and terrestrial origin duly corrected for the relative motion of Jupiter, the Sun, and the Earth.

The planets of the solar system may be divided into two groups: the major planets—Jupiter, Saturn, Uranus, and Neptune—and the terrestrial planets. The planets in each one of these groups are remarkably different from those in the other in size, appearance, motion, and distance from the Earth. Astronomers who first examined spectroscopically the sunlight reflected by the planets'

surfaces noticed that the major planets exhibited dark bands in the orange and red regions of the spectrum which were not visible in the spectra of the terrestrial planets.

Modern photographic observations have confirmed the existence of these bands and have revealed similar bands in the infrared portion of the spectrum. They have been interpreted by R. Wildt<sup>2</sup> as absorptions by ammonia and methane gases in the planets' atmospheres. In 1933 at Mt. Wilson Observatory near Pasadena, Calif., T. Dunham<sup>3</sup> verified Wildt's interpretations by photographing, side by side, high-dispersion spectra of Jupiter and of white light transmitted through a long tube containing ammonia and methane at high pressure. In all this work, however, there appear to be no detailed descriptions of the structures of the bands, based on measurements of their lines, beyond those reported by Slipher in 1905 at the Lowell Observatory at Flagstaff,



Jupiter as drawn by Barnard in 1880 at Lick Observatory on Mount Hamilton, Calif. Great Red Spot is in southern hemisphere.

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Ariz. and in the more recent paper by Bobrovnikoff (1933).

At the time the photographs were taken for the present analysis, Jupiter was receding from the Earth with a relative velocity of 22 km/sec. This motion was considered great enough that any absorption lines due to oxygen or water vapor in Jupiter's atmosphere would be separated on the spectrograms, by means of the Doppler effect, from those produced in the Earth's atmosphere. In the spectrograms the lines of planetary origin were shifted toward the longer wavelengths and also slanted with respect to those of terrestrial origin as a result of Jupiter's orbital and rapid axial rotation. Thus lines of  $O_2$  and  $H_2O$ , if present in Jupiter's spectrum, could be distinguished easily from those originating on Earth. However, no such lines were detected.

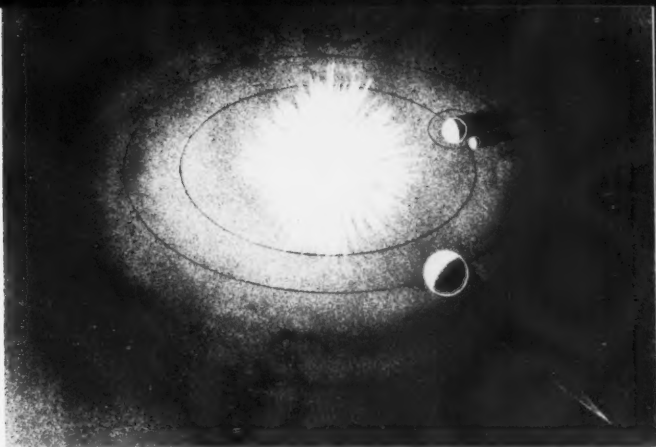
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The ammonia molecule has two absorption bands in the regions observed—one at 6450 Å in the red and one at 7900 Å in the infrared. In the 6450 Å band, 49 lines were observed of which 47 were identified with ammonia lines published by Chao in 1936.<sup>4</sup> In the 7900 Å band, 136 lines were observed of which 113 were identified with the published lists of ammonia lines.

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The methane molecule absorbs light at 6200, 7250, 8420, and 8620 Å. The identification of the methane bands in Jupiter's spectrum was made by Wildt with less supporting laboratory evidence than was available for the ammonia bands. Verification of his identifications was not forthcoming until the experimental results of Dunham appeared. Subsequently, Vedder and Mecke (1933)<sup>5</sup> resolved the structure of the methane bands at 8620, 8420, and 7250 Å. However, no wavelengths in the planetary bands had been measured that would make possible a line-by-line comparison with bands produced in the laboratory.

The present investigation includes the measurement of 94 lines in Jupiter's bands at 7250, 8420, and 8620 Å. Only about one-third of these are



Positions of the Sun, Jupiter, Earth, and Moon represented for May 1957, when Jupiter was photographed. (Object and orbital diameters not to true scale.)

identifiable with lines in the published lists of Vedder and Mecke's observations. Each list contains many lines not to be found in the other; this situation is probably a result of formation of the lines under different conditions of temperature and pressure.

In the  $CH_4$  band at 6200 Å, 23 lines were measured; but no laboratory data are available for comparison.

#### 

Although molecular hydrogen has long been regarded as one of the constituents of Jupiter's atmosphere, spectrographic evidence of its presence is lacking. Nevertheless, the low mean density of the planet ( $1/4$  that of the Earth) can be explained only by assuming the presence of hydrogen.

Spectrographic detection of molecular hydrogen in planetary atmospheres is difficult because its electronic transitions that form absorption lines lie in the far ultraviolet beyond the regions of astronomical observation. In 1938, G. Herzberg<sup>6</sup> suggested that molecular hydrogen might be detected through its quadrupole rotation-vibration spectrum if the depth of the gas in the atmosphere of Jupiter is as large as 10 or 15 mi at a pressure of 1 atm.

In experiments at the Yerkes Observatory at Williams Bay, Wis., Herzberg succeeded in measuring the strongest lines in two bands of the spectrum, one of which lies within the range of the present observations. Four lines in the (3,0) band as measured by Herzberg are at 8497.49, 8272.69, 8150.68, and 8046.44 Å. The corresponding lines observed in the present investigation are at 8497.52, 8272.60, 8150.66, and 8046.44 Å. An analysis of the contours of these lines by Zabriskie at the Princeton University Observatory yielded a value of 5 km-atm of molecular hydrogen above the cloud layer of Jupiter.

### Absorption in the Violet and Ultraviolet Regions

Prominent in the spectrum of Jupiter is the general absorption that occurs in the violet and ultraviolet regions. The absorption begins near 4200 Å and increases in strength with decreasing wavelength until it blots out the planet's spectrum a little short of 3800 Å.

With the cooperation of F. J. Heyden, S.J., of the Georgetown College Observatory, additional spectrograms of Jupiter and of the Moon were obtained in early 1959 to extend the observations to 3600 Å. In this spectral region, the brightness of Jupiter is reduced by one-half relative to that of the Moon for every decrease of 135 Å in wavelength. The identity of the particle responsible for this short-wave absorption is important, as it may play a role in the physical chemistry of the planet's atmosphere. Vogel observed the effect repeatedly and called attention to its fluctuation in strength with the changes in color of Jupiter's belts and bands.

It seems probable that, if it is a molecule, the particle is a compound of the gases normally present in a planetary atmosphere. Kuiper (1952) has given a list of such compounds, but none has a continuous absorption band resembling that in Jupiter's spectrum. However, the band described by Harris (1928), by Hall and Blacet (1952), and by others for nitrogen tetroxide, the low-tempera-

ture polymer of nitrogen dioxide, fits the Jovian band almost exactly.

In suggesting that this molecule may be present in Jupiter's atmosphere and that it may be responsible for the variable color patterns observed there, one must be aware of the objection that oxides of nitrogen are readily reduced in the presence of hydrogen and ammonia. However, both  $\text{NO}_2$  and  $\text{N}_2\text{O}_4$ , sometimes designated jointly as nitrogen peroxide, are much heavier than either  $\text{H}_2$  or  $\text{NH}_3$ . It therefore seems possible that gravitational separation of the gases alone may be sufficient to maintain a layer of the oxides at a depth in the planet's atmosphere adequate to prevent or minimize the reducing action of the lighter gases existing in the outermost regions.

<sup>1</sup>For further information see High-dispersion spectra of Jupiter, by C. C. Kieck, C. H. Corliss, and Harriet K. Kieck, *Astrophys. J.* **132**, 221 (1969).

<sup>2</sup>Absorptionsspektren und Atmosphären der grossen Planeten, by Rupert Wildt, *Veröff. der Univ. Sternkarte Göttinger* **2**, **22**, 171 (1932).

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## Power Loss of Tires

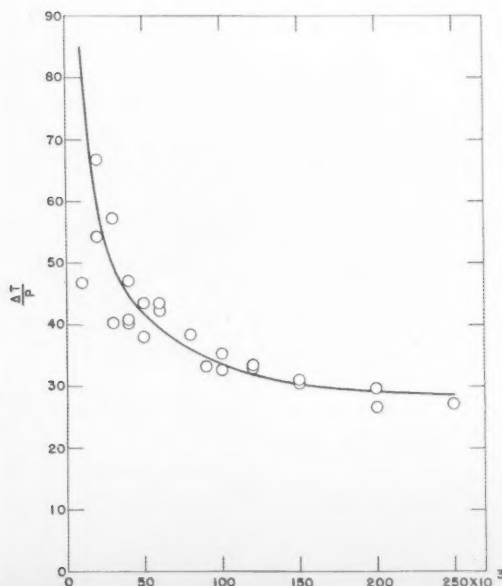
A STUDY of the power loss of tires under controlled laboratory conditions has been completed for the Federal Facilities Corp. Experi-

mental results show that tire construction and type of rubber are the main factors determining the manner in which power loss varies with changes in speed, load, and inflation pressure. Measurements of power loss obtained in the study provide data needed in future tire design and development.<sup>1</sup>

The high operating temperatures that result from the power loss of tires often cause premature failure. Although the problem has long been recognized, few systematic studies of power loss have been made. The high speeds maintained for protracted periods on the highways today, as well as contemplated changes in tire design and the possible use of new polymers and cords in tire construction, have emphasized the need for quantitative data on tire performance obtained under controlled laboratory conditions. To provide such data, R. D. Stiehler and coworkers of the Bureau staff undertook the present study.

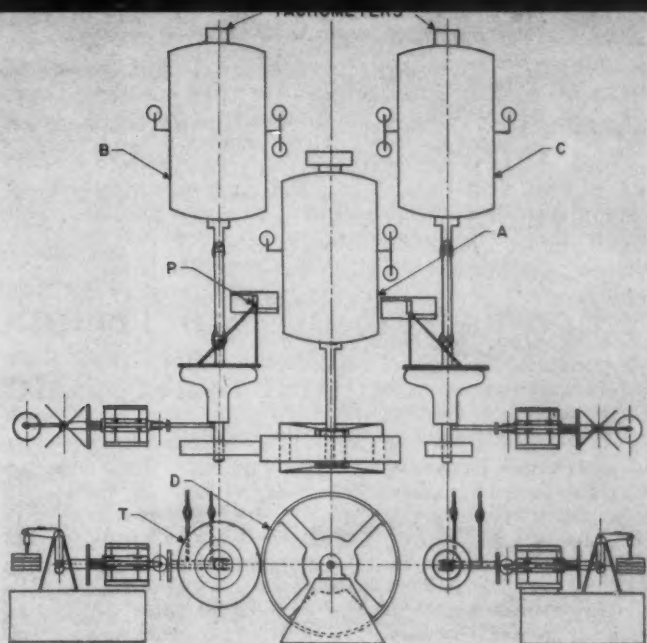
In the equipment used for the experiments, power loss in large-size tires was measured with

Data obtained from study of power loss in a truck tire, showing how temperature rise of air within the tire per unit power loss ( $\Delta T/P$ ) is affected by changes in products of speed and load (SL).





Schematic arrangement of equipment for measuring power loss of tires: A—Absorption dynamometer connected to steel drum; B—Dynamometer for driving truck tire, *T*; C—Dynamometer for driving passenger car tire; and P—Ball and socket pivot for alining plane of tire with plane of drum.



two dynamometers, one for power output and the other for power input. The first dynamometer, which provided the necessary tractive effort, was connected to a steel drum; the second, to a truck tire assembly located next to the steel drum. The plane of the tire was alined with the plane of the drum. Load was applied to the tire by weights acting through a lever arm which forced the tire against the drum.

To evaluate passenger-car tires, a standard-size tire assembly connected to a third dynamometer was mounted on the other side of the steel drum, and operated in a manner similar to that of the truck-tire assembly. Both of the dynamometers connected to the tire assemblies were instrumented to permit measurement of speed to within 0.1 rpm, and of torque to within 1.0 percent of the difference between input and output torques.

The equipment was enclosed in a housing so that the temperature of the atmosphere could be controlled. A previously developed method, in which a copper-constantan thermocouple is inserted through the tire valve,<sup>2</sup> was used to measure the temperature of the air contained in the tire under study. To measure inflation pressure, the valve stem of the specimen was connected through a rotating joint to a precision pressure gage.

In the experiments the specimen was first preconditioned by rotation against the drum for 16 hr at 45 mph under 80 to 100 percent of maximum load. After preconditioning, the load, speed, and inflation pressure were adjusted to the desired values; the axle of the rotating tire was made parallel to the axle of the steel drum; and the tire was run until the temperature of the contained air remained constant. Readings were then taken of the torque on the dynamometers, their speed, and

the inflation pressure, and the temperatures of the ambient air and of the contained air were recorded. For convenience in comparing the specimens, the rolling resistance coefficient  $R$ —a dimensionless quantity—was used. It was derived from the equation

$$R = P / SL,$$

in which  $P$  is power loss in foot-pounds per minute,  $S$  is speed in feet per minute, and  $L$  is load in pounds.

In the present study, experiments were conducted at speeds of 5 to 50 mph under constant loads of 1,000 to 5,000 lb at inflation pressures of 60 to 120 lb/in<sup>2</sup>. Rolling resistance data were compiled for tires varying from 7.00–15 passenger-car size to 11.00–20 truck size, constructed either of natural or synthetic rubber or a combination of both, containing 1 of 7 different kinds of carbon black, and having rayon, nylon, or steel wire cords.

An analysis of the data showed that the rolling resistance coefficient of passenger-car tires was greater than that of truck tires. The effect of inflation pressure on  $R$  was practically independent of speed at normal loads, but markedly dependent on speed at low loads. In the truck tires studied having either nylon cord or steel wire cord, a decrease in  $R$  occurred with increasing speed; tires with rayon cord showed either no change or a linear increase in  $R$  with increasing speed. In passenger-car tires  $R$  increased at a growing rate with increasing speed, particularly in a rayon cord tire.  $R$  increased with load in all but steel wire cord truck tires.

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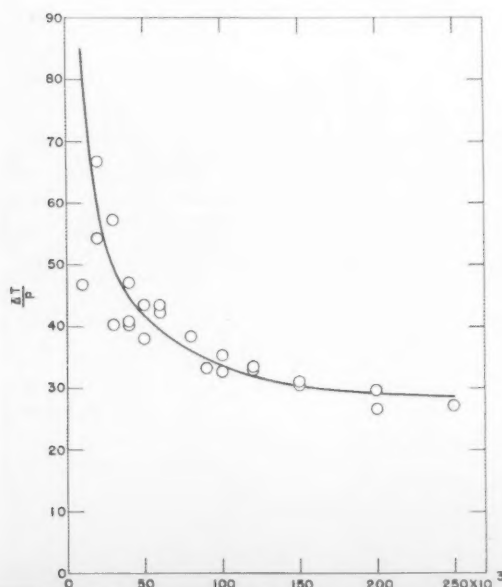
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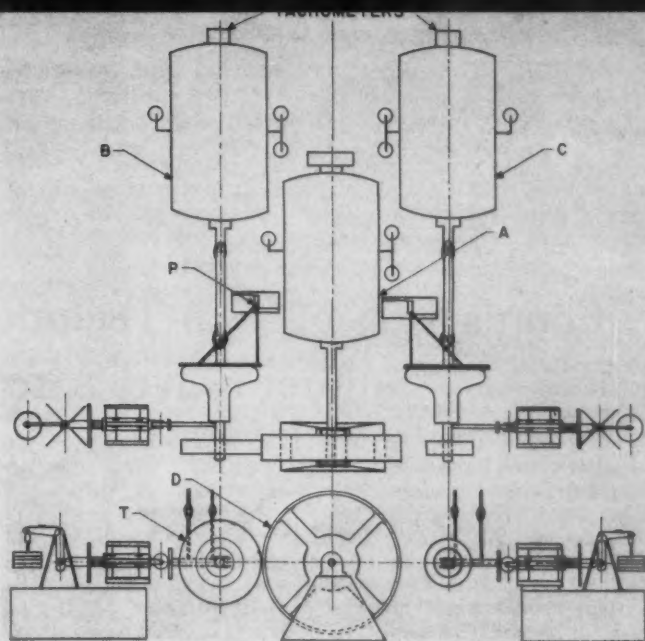
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ber (SBR). When natural rubber was substituted for SBR in either the tread or the carcass of a tire, the resulting decrease in power loss was not as large as would be anticipated from a comparison of 100 percent natural rubber tires with 100 percent SBR tires. The operating temperature of a tire was found to depend on power loss and on the thermal conductivity of the rubber, as

well as on speed, load, and ambient temperature.

<sup>1</sup>For further technical details see Power loss and operating temperature of tires, by R. D. Stichler, M. N. Steel, G. G. Richey, J. Mandel, and R. H. Hobbs, *J. Research NBS* 64C, 1 (1960).

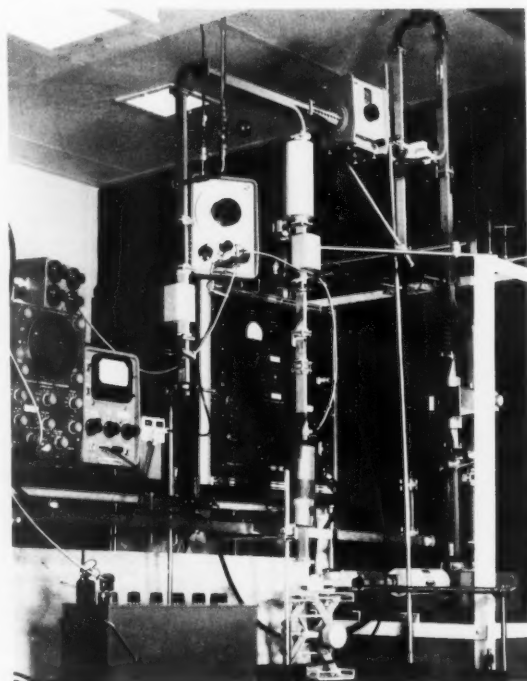
<sup>2</sup>Temperature studies of the air in a truck tire, by G. G. Richey, R. H. Hobbs, and R. D. Stichler, *Rubber Age* 79, 273 (1956); and Direct measurement of tire operating temperatures, *NBS Tech. News Bul.* 41, 76 (1957).

## Comparison of Two Techniques for Measuring Microwave Attenuation

**T**WO METHODS of measuring microwave attenuation have recently been compared at the Bureau's Radio Standards Laboratory at Boulder, Colo., by a technique that virtually eliminates environmental influences.<sup>1</sup> Both techniques were developed by the microwave circuit standards laboratory; one is an ultraprecise power attenuation measurement system,<sup>2</sup> and was used as the reference in testing the second technique, a recently developed subcarrier system for measuring attenuation.<sup>3</sup> Both systems are significantly more precise than other methods now in use, and the comparison shows that measurements made with the two agree within 10 microbels.

Both attenuation measurement methods use a two-channel waveguide system. The low power required by the subcarrier technique may be "borrowed" from a power measurement system by directional couplers without disturbing the latter. Thus the test attenuator can be placed in one channel which is common to both systems. This technique eliminates environmental effects and mismatch errors, and minimizes re-settability limits of the attenuator when making comparisons.

Ronald R. Bowman adjusts microwave variable attenuator in modulated subcarrier attenuation measurement system.



Above: Composite arrangement of d-c and subcarrier methods where attenuator is in channel common to both systems. Differences as small as 10 microbels were observed with this arrangement.

The power measurement portion of the system was operated by G. F. Engen, the modulated subcarrier portion by G. E. Schafer. Necessary matching procedures were carried out by R. W. Beatty.

The attenuator used in the comparison was a rotary vane, WR-90 waveguide variable attenuator and the measurements were performed at 9.4 Gc/s. The precision of the modulated subcarrier method was approximately 0.0005 db at low values of relative attenuation and decreased to about 0.005 db at 20-db relative attenuation.

The standard attenuator used in the subcarrier method is a voltage ratio transformer. It is not possible at present to obtain calibrations that are

#### *A test of the modulated subcarrier technique of measuring microwave attenuation*

Results of measuring relative attenuation simultaneously by subcarrier and modified d-c methods.

Dial reading	Measured attenuation	Difference between subcarrier and d-c
<i>db</i>	<i>db</i>	<i>db</i>
0.01-----	0. 0110	+0. 0002
.02-----	. 0214	-. 0002
.05-----	. 0523	-. 0001
.10-----	. 1028	+. 0005
.50-----	. 4978	+. 0001
1.0-----	1. 0030	-. 0012
2.0-----	1. 9980	-. 0003
5.0-----	4. 9890	-. 0011
10.0-----	9. 9609	+. 0012
20.0-----	19. 9606	+. 0066

## 1960 CRYOGENIC ENGINEERING CONFERENCE

**M**ORE THAN 750 scientists and engineers, representing industry, government, and universities, attended the 1960 Cryogenic Engineering Conference held August 23, 24, and 25 at Boulder, Colo. The University of Colorado and the Bureau's Boulder Laboratories jointly sponsored the conference. The nine technical sessions dealt with cryogenic engineering theory, current research, and the relationship of the field to the subject of space technology, as well as transfer, physical equilibria and related properties of low temperature gases, practical applications, processes, and equipment in the field of extreme low temperature engineering.

Dr. Robert B. Jacobs, of the Bureau's cryogenic engineering laboratory and chairman of the conference, called the meeting to order; Dr. F. W. Brown, Director, Boulder Laboratories, and Dr. O. Tippo, Provost of the University of Colorado, each gave a brief welcoming speech.

as accurate as is theoretically possible with this type of standard, but the results of this test indicate that the accuracy of the standard is at least comparable to the precision attained by the subcarrier method. Therefore, this particular transformer as well as others similar to it can be used as a standard attenuator in the subcarrier system.

The refined power measurement method alone had indicated earlier that the accuracy of relative attenuation measurements exceeds the precision to which microwave attenuators can be set and read. The present comparison firmly substantiates this observation. Expanded scales and precision gears will be needed on future variable microwave attenuators in order to realize more fully the possibilities for accuracy in both of these systems.

<sup>1</sup> For further technical information, see Microwave attenuation measurements with accuracies from 0.0001 to 0.06 decibel over a range of 0.01 to 50 decibels, by G. F. Engen and R. W. Beatty, *J. Research NBS* **64C**, No. 2, 139 (April-June 1960).

<sup>2</sup> Ultraprecise attenuation measurement, *NBS Tech. News Bul.* **43**, No. 12, 230 (December, 1959).

<sup>3</sup> A modulated subcarrier technique of measuring microwave attenuation, by G. E. Schafer and R. R. Bowman, presented to Commission I Session, *URSI-IRE Spring Meeting*, May 2-5, 1960.



### *Space Technology*

The first session, Tuesday morning, August 23, opened with an invited paper on the current status of electric propulsion systems including ion and plasma accelerators with regard to space missions, by W. E. Moeckel (National Aeronautics and Space Administration). Captain G. J. Murphy, USAF (Air Force Ballistic Missile Division) presided over the session.

Three of the contributed papers at the space technology session dealt with an area in which cryogenic engineering makes a large contribution to space engineering—insulation of cryogenic fluids. The topics included: Cryogenic rocket insulation systems, R. J. Frainier (Linde Co.); development of high-efficiency insulation techniques for cryogenic fluids, I. A. Black and P. E. Glaser



(Arthur D. Little, Inc.); and the improvement of evacuated aerogel powder insulation, W. H. Power (Monsanto Chemical Co.). Back-diffusion, or a flow counter to the flow in the vapor vent-line in a cryogenic-fluid storage tank, was the topic of the final paper of this session, presented by B. A. Buffham and B. M. Bailey (Air Products, Inc.). Back-diffusion occurs when components are present in greater concentration in the atmosphere than in the vapor space of the tank; analytical approaches and experimental work for making quantitative predictions of the effect of back-diffusion on long-term storage of cryogenic liquids were discussed.

### *Applications*

A concept of an airborne helium cryostat of high thermodynamic efficiency to be used in spaceborne cold sinks for deep cooling of cryotronics was described by G. A. Zotos (The Martin Co.) in a paper delivered at the session on applications Tuesday afternoon, August 23. Performance, potential, and reliability of the cryostat were discussed. C. F. Squire (Rice Institute) presided at the applications session.

A presentation on the principle of a liquid nitrogen irradiation device, its possible use in a swimming-pool type of reactor, its high reliability and total elimination of explosion hazards was offered. L. Bochirol, J. Doulat, and L. Weil (Commissariat à l'Énergie Atomique, Centre d'Études Nucléaires de Grenoble) described main features of the device, which include a double nitrogen bath, gravity flow-back, low nitrogen consumption, and provision for removing irradiated samples in the cold condition.

Two refrigeration systems were discussed at this session. A compact Joule-Thomson system, providing  $\frac{1}{2}$  to 2 w of useful refrigeration in the 15- to 60-°K range, was described by J. M. Geist and P. K. Lashmet (Air Products, Inc.). Nitrogen-hydrogen and nitrogen-neon refrigerators, and closed-cycle and once-through systems were described.

W. E. Gifford and T. E. Hoffman (Arthur D. Little, Inc.) presented a new refrigeration system for 4.2 °K which has displacers, two valves, no pistons, requires only a low pressure gas, and gives promise of great reliability due to its fundamental simplicity.

Also presented at this session were a paper on recently developed small superconducting cryogenic motors, by K. F. Schoch (General Electric Co.); a discussion of a cryogenic gyroscope by J. T. Harding and R. H. Tuffias (California Institute of Technology); and a summary of past and present criteria used in selection of lubricants and thread compounds for missile oxygen systems, plus an account of efforts at standardization in this field, by C. H. Reynales (Space Technology Laboratories).

### *Panel Discussion on Superconductivity*

A panel discussion on superconductivity was held Tuesday evening, August 23, in the Boulder Laboratories auditorium, with S. C. Collins (Massachusetts Institute of Technology) presiding. Panel members and their topics were: T. A. Buchold (General Electric Co.), applications of superconductivity; J. R. Purcell (NBS Cryogenic Engineering Laboratory), superconducting rectifiers; E. Maxwell (Lincoln Laboratory, Massachusetts Institute of Technology), superconducting cavities and other superconducting applications; and V. D. Arp (NBS Cryogenic Engineering Laboratory), superconducting electromagnets.

### *Processes*

A highly successful plant for the production of liquid hydrogen from refinery waste gas was described by P. D. Fuller (Stearns-Roger Manufacturing Co.) and W. E. Gifford (Arthur D. Little, Inc.) at the Wednesday morning August 24 session on processes. Two sections of the plant, purification and liquefaction, were described, as were its continuous, relatively trouble-free performance periods of 24 hr/day, 7 days/week, for up to 67 days without shutdown. O. L. Hough (Stearns-Roger Manufacturing Co.) presided.

Experiments performed by the U.S. Bureau of Mines on the explosion hazards of liquid hydrogen were discussed by M. G. Zabetakis, A. L. Furno, and G. H. Martindill, at this session. The greatest hazards found in this study, exclusive of those associated with the freezing of air in liquid hydrogen and the ignition of confined flammable hydrogen-air mixtures, arose from the rapid production of flame and radiant energy following ignition of the hydrogen-air mixtures above a spill area.

The use of cryogenic fluids to operate two-phase pumps is one of the most efficient methods of achieving high pumping rates for use in space simulation facilities, according to a paper by W. W. Balwanz, J. M. Singer, and N. P. Frandsen (U.S. Naval Research Laboratory).

Other papers delivered during the session on processes included the following: On comparison of liquid pumping and gas compression in gas-producing oxygen plants, by D. E. Smith (Air Reduction Co., Inc.); on dynamic seals for cryogenic fluids, by D. W. Wisander and R. L. Johnson (NASA); on static seals for cryogenic fluids, by D. H. Weitzel, R. F. Robbins, and G. R. Bopp (NBS Cryogenic Engineering Laboratory); and on unconventional bearing lubricants for cryogenic applications, by D. H. Tantam and R. Hargreaves (British Oxygen Research and Development Ltd.).

### *Transfer Phenomena*

In the parallel session Wednesday morning, August 24, at which J. W. Marshall (Edwards



AFB) presided, seven papers were delivered on the subject of transfer phenomena. Six of these dealt with various problems and procedures connected with transfer of cryogenic fluids by pressurization, and brought out the following points:

(1) In removal of cryogenic fluids from a storage vessel by pressurization, an analytical method for estimating the gas requirements was stated, by D. C. Bowersock and R. C. Reid (A. D. Little, Inc.), to be probably superior to any of the empirical methods commonly used, although application of the analytical method is somewhat more difficult.

(2) An electronic computer has been used experimentally to figure the decrease of pressure as a cryogenic fluid is withdrawn by the gas pressure method, according to J. M. Canty (Linde Co.).

(3) Gaseous oxygen being used for pressurized transfer of cryogenic fluids (liquid rocket propellants) from tanks in liquid nitrogen baths has been analyzed and equations derived and checked, to predict the rate of condensation of the gases used for pressurization, as reported by J. C. Humphrey (NASA).

(4) Exact thermodynamic equations have been established for pressure variations in a vented tank being filled with liquid oxygen, and also when the initial flow is gaseous oxygen followed by liquid oxygen, according to D. G. Burkhard, W. H. Clohessy, and W. E. Brittin (University of Colorado).

(5) Wall and fluid temperature responses during the pressurized discharge of a liquid from a container have been analyzed as to constant temperature, and adiabatic and time dependent heat flux, and were reported by V. S. Arpacı, J. A. Clark, and W. O. Winer (University of Michigan) to be valid for cryogenic containers.

(6) Line cooldown times for composite piping systems (for example, piping systems containing vertical as well as horizontal sections, as in recently designed cryogenic missile loading systems) could not be predicted analytically; an experimental program, reported in a paper by E. M. Drake, F. E. Ruccia, J. M. Ruder (Arthur D. Little, Inc.), has now substantiated that these line cooldown times can be predicted for the composite systems by the same techniques used previously for horizontal systems.

The seventh paper, by W. K. Sutton and W. H. LeValley (Linde Co.), described in detail a typical piping system for cryogenic fluids designed during a comprehensive program on vacuum insulated piping undertaken by that company.

### Equipment

A closed-cycle Helium<sup>3</sup> refrigerator, designed for use with a microwave resonance spectrometer, was described by C. J. Rauch (Lincoln Laboratory, Massachusetts Institute of Technology) in one of the papers delivered at the session on equipment, Wednesday afternoon, August 24. The re-



Captain G. J. Murphy, Air Force Ballistic Missile Division, and Robert B. Jacobs, of the NBS Cryogenic Engineering Laboratory, at the Space Technology Session of the 1960 Cryogenic Engineering Conference. Capt. Murphy chaired the session and Mr. Jacobs was chairman of the Conference.

frigerator uses a recently constructed temperature entropy diagram for Helium<sup>3</sup> in the mixed phase region of liquid and vapor below 2 °K; an ultimate temperature of 0.35 °K is expected.

C. H. Trent (Aerojet-General Corp.) served as chairman of this session.

The performance of infrared detection cells is often greatly improved by cooling them to cryogenic temperatures; developments in new detector cooling devices were reported in two papers at this session, one by G. C. Haettinger, R. P. Skinner, and R. A. Trentham (Linde Co.) with emphasis on design considerations, and one by J. S. Tyler and J. A. Potter (AiResearch Manufacturing Co.), centering on the performance characteristics of systems currently being developed.

Design details and thermal performance of a cryostat for use with standard tensile testing equipment for the temperature range 4 to 300 °K were presented by R. M. McClintock and K. A. Warren (NBS Cryogenic Engineering Laboratory).

Two additional papers delivered at the equipment session dealt with high-accuracy temperature measurement (Pratt & Whitney Aircraft) and flowmeter calibration stands for cryogenic liquids (Wyle Laboratories). These were by J. W. Ladd and L. N. Mortensen, respectively.

## Physical Equilibria and Related Properties

Several methods which have been used to compute the vapor phase composition and to predict its equilibrium in a pressurized, two-component (hydrogen-methane) system were discussed in a paper by B. S. Kirk, W. T. Ziegler, and J. C. Mullins (Georgia Institute of Technology) at the parallel session Wednesday afternoon, August 24, with C. McKinley (Air Products, Inc.) occupying the chair. The work, partly supported by the Bureau's Cryogenic Engineering Laboratory, assumed an equation of state for the gas phase, and used as a parameter the "enhancement factor" (ratio of the partial pressure to the vapor pressure of the condensed component).

A study, reported by W. H. Mueller, R. Kobayashi, and T. W. Leland (Rice Institute), in which the principle of corresponding states for mixtures was extended to mixtures of low molecular weight gases at low temperatures, and a continuing study, reported by Z. Dokoupil (University of Leiden, Netherlands), on the phase equilibrium of the nitrogen-hydrogen system at temperatures and pressures below those which are critical for hydrogen, comprised additional papers delivered at the same session.

An equation of state useful in representing the mechanical properties of a fluid (hydrogen) was reported by R. D. Goodwin of the Bureau's Cryogenic Engineering Laboratory. The simple equation was presented as an approximation and, while not adequate for thermodynamic computations, is useful, if valid over a wide range, in providing a continuous norm for comparing experimental data for purposes of smoothing.

Other papers provided information on the adsorption of methane on silica gel at low temperatures, as presented by M. J. Hiza and A. J. Kidnay (NBS Cryogenic Engineering Laboratory), and data on the phase equilibria of two component systems, reported by C. J. Sterner (Air Products, Inc.).

## Heat Transfer and Thermometry

A paper by D. E. Ward (British Oxygen Engineering, Ltd.) Thursday morning, August 25, on aspects of the design and operation of low temperature regenerators to be used as purification units, concludes that the regenerator is preferred to the reversing exchanger except in special cases, particularly where pure products are handled. A. A. Fowle (Arthur D. Little, Inc.) held the chair at the session on heat transfer and thermometry.

A final report on the calculation of thermocouples of gold-cobalt or constantan versus "normal" silver or copper, a discussion of the techniques and reliability of spot calibrations, and a preliminary report on other commercial thermocouple metals and progress toward new materials of greater reliability at low temperatures, made up a paper by R. L. Powell, M. D. Bunch, and

L. P. Caywood (NBS Cryogenic Engineering Laboratory).

Results useful in the field of secondary thermometry, derived from further experiments on the calibration reproducibilities at 4.2 °K of carbon and germanium resistors, were reported by M. H. Edlow and H. H. Plumb (NBS).

K. E. Leonhard and R. McMordie (Boeing Airplane Co.) reported on a theoretical and experimental study of the two-phase annular flow of an evaporating cryogenic fluid through a horizontal tube. The mathematical description is developed in terms of an interface friction factor.

Other papers dealt with single tube heat transfer tests with liquid hydrogen, as reported by H. H. Walters (AiResearch Manufacturing Co.); heat transfer of boiling liquid hydrogen, as brought out in a study by R. W. Graham, R. C. Hendricks, Y-Y. Hsu, and R. Friedman (NASA); and heat and mass transfer to uninsulated oxygen containers, presented by D. C. Holten (NBS Cryogenic Engineering Laboratory).

## Mechanical Properties

The localized action of fatigue in austenitic stainless steel (merely developing pre-existing cracks) was confirmed by a study reported by J. Menard and L. Weil (University of Grenoble) at the parallel session Thursday morning, August 25. Gamma to alpha transformation in the steel was studied under both single and repeated stresses at temperatures down to 20 °K. E. L. McCandless (Linde Co.) presided at this session.

Also reporting on the mechanical properties observed in austenitic stainless steels at temperatures down to 20 °K was a paper by C. J. Guntner and R. P. Reed (NBS Cryogenic Engineering Laboratory).

Two cryostats for testing certain mechanical properties of metals at cryogenic temperatures were reported and described, one by T. S. DeSisto and F. L. Carr (Watertown Arsenal Laboratories) and the other by K. Mendelssohn (The Clarendon Laboratory).

Tests on toughness, fatigue properties, and weldability of aluminum alloys at low temperatures were the subjects of papers by F. W. DeMoney and G. C. Wolfer (Kaiser Aluminum and Chemical Corp.) and by J. L. Christian and J. Watson (Convair-Astronautics) at the same session.

A simple hardness test by which the relative crystallinity of fluorinated plastics can be determined quickly and accurately was described by R. Mowers (Rocketdyne). The effectiveness of the room temperature hardness test in predicting the mechanical properties of the various materials at cryogenic temperatures was demonstrated.

## Luncheon Addresses

Among the highlights of the conference were the two luncheon addresses.

Dr. R. W. Spence of the Nuclear Propulsion Division, Los Alamos Scientific Laboratory, addressed the luncheon meeting Tuesday, August 23, in the Glenn Miller Ballroom of the Colorado University Memorial Center. Dr. Spence's subject was "Nuclear Rockets, their Concept, Progress, and Impact on Future Missile Programs."

Dr. E. U. Condon, former director of the National Bureau of Standards, and now Wyman Professor of Physics, Washington University, delivered the principal address of the 1960 conference, speaking on "Scientific Technology and Engineering Education" at the Wednesday luncheon meeting, August 24. Dr. Condon pleaded for emphasis on basic science in engineering education, urging university professors to do all in their power toward that end, and calling on employers

and supervisors of men working on advanced technological projects, to aid in "the coming transformation in engineering education in order to assure continued American leadership in the technological progress of the world..." Dr. Condon added that "... we need to train our young engineers to keep in the closest possible touch with progress at the scientific frontiers, in order that we may make the best utilization of that knowledge for human welfare in the quickest possible time."

### Additional Papers Accepted

Twelve additional papers were accepted by the Conference Committee and, with the papers delivered at the Conference, will be included in the published proceedings, *Advances in Cryogenic Engineering*, volume 6, which will be available from Plenum Press, Inc., early in 1961.

## Publications of the National Bureau of Standards

### Periodicals

*Technical News Bulletin*, Volume 45, No. 10, October 1960. 15 cents. Annual subscription: \$1.50, 75 cents additional for foreign mailing. Available on a 1-, 2-, or 3-year subscription basis.

*Basic Radio Propagation Predictions* for January 1961. Three months in advance. CRPL-D194, issued October 1960. 15 cents. Annual subscription \$1.50, 50 cents additional for foreign mailing. Available on a 1-, 2-, or 3-year subscription basis.

*Journal of Research of the National Bureau of Standards* Section A. Physics and Chemistry. Issued six times a year. Annual subscription: Domestic, \$4; foreign, \$4.75.

Section B. Mathematics and Mathematical Physics. Issued quarterly. Annual subscription: Domestic, \$2.25; foreign, \$2.75.

Section C. Engineering and Instrumentation. Issued quarterly. Annual subscription: Domestic, \$2.25; foreign, \$2.75.

Section D. Radio Propagation. Issued six times a year. Annual subscription: Domestic, \$4; foreign, \$4.75.

### Nonperiodicals

The metric system of measurement, NBS Misc. Publ. 232 (1960) 50 cents. Standard X-ray diffraction powder patterns, H. E. Swanson, M. I. Cook, E. H. Evans, and J. H. deGroot. NBS Circ. 539, vol. 10 (1960) 40 cents.

### Technical Notes

The following Technical Notes are available from the Office of Technical Services, U.S. Department of Commerce, Washington 25, D.C. (Order by PB number). Investigation of bearing creep of two forged aluminum alloys, L. Mordfin, N. Halsey, P. J. Granum. NBS TN55 (PB161556) (1960) \$1.00.

Rapid determination of the order of chemical reactions from time-ratio tables, J. H. Flynn. NBS TN62 (PB161563) (1960) 75 cents.

Radio refractometry, J. W. Herbstreit. NBS TN66 (PB161567) (1960) 50 cents.

Low- and very low-radiofrequency model ionosphere reflection coefficients, J. R. Johler, L. C. Walters, J. D. Harper, Jr. NBS TN69 (PB161570) (1960) \$2.00.

### Publications in Other Journals

Halobenzenes as sensitizers for the radiation-induced polymerization of styrene, D. W. Brown and L. A. Wall, *J. Polymer Sci.* 44, 325-340 (June, 1960).

Some aspects of fluorine flame spectroscopy, D. E. Mann. Proc. propellant thermodynamics and handling conf. Special Rept. 12 (Ohio State Univ., Columbus, Ohio, June, 1960).

Optical constants of aluminum, H. Mendlowitz. Proc. Phys. Soc. (London, England) LXXV, 664-670 (1960).

Current thermodynamic research on light-element compounds at the National Bureau of Standards, T. B. Douglas. Proc. propellant thermodynamics and handling conf. Special Rept. 12 (Ohio State Univ., Columbus, Ohio, June, 1960).

Free radicals in gamma-irradiated polystyrenes, R. E. Florin, L. A. Wall, and D. W. Brown. *Trans. Faraday Soc.* 56, No. 453, 1304-1310 (September, 1960).

Sealed-off Hg<sup>198</sup> atomic-beam light source, R. L. Barger and K. G. Kessler. *J. Opt. Soc. Am.* 50, No. 7, 651-656 (July, 1960).

Temperature dependence of Young's modulus of vitreous germania and silica, S. Spinner and G. W. Cleek. *J. Appl. Phys.* 31, No. 8, 1407-1410 (1960).

Atomic clocks for space experiments, P. L. Bender. *Astronautics*, p. 69-71 (July, 1960).

Photolysis of ammonia in a solid matrix at low temperatures, O. Schnepf and K. Dressler. *J. Chem. Phys.* 32, No. 6, 1682-1686 (June, 1960).

Photochemical rates in the equatorial F<sub>2</sub> region from the 1958 eclipse, T. E. Van Zandt, R. B. Norton, and G. H. Stonehocker. *J. Geophys. Research* 65, No. 7, 2003-2209 (July, 1960).

Influence of source distances on the impedance characteristics of ELF radio waves, J. R. Wait. *Proc. IRE* 48, No. 7, 1338 (July, 1960).

Electroless plated contacts to silicon carbide, R. L. Raybold. *Rev. Sci. Instr.* 31, No. 7, 781-782 (July, 1960).

Statistical models for component aging experiments, J. R. Rosenblatt. *Intern. Conv. Record, IRE*, 8, Pt. 6, 115-124 (1960).

Isotope effect in the hydrogen atom-formaldehyde reaction, J. R. McNesby, M. D. Scheer, and R. Klein. *J. Chem. Phys.* 32, No. 6, 1814-1817 (June, 1960).

Electric current and fluid spin created by the passage of a magnetosonic wave, R. P. Kanawal and C. Truesdell. *Arch. Rational Mech. and Analysis*, 5, No. 5, 432-439 (1960).

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- The nature of the inorganic phase in calcified tissues, A. S. Posner. *Calcification in Biological Systems*, p. 373-394 (American Assoc. Advancement of Sci., Washington, D.C., 1960).
- Effect of water-reducing admixtures and set-retarding admixtures on properties of concrete, Introduction and Summary, B. E. Foster. *Am. Soc. Testing Materials Spec. Tech. Publ. 266*, Introduction 1 & 2 and Summary 240-246 (June, 1960).
- Adsorption spectra of solid methane, ammonia, and ice in the vacuum ultra-violet, K. Dressler and O. Schnepf, *J. Chem. Phys.* **33**, No. 1, 270-274 (July, 1960).
- The extent of HII regions, S. R. Pottasch, *Astrophys. J.* **132**, No. 1, 269-271 (July, 1960).
- Nickel oxide thin film resistors for low pressure shock wave detection, K. E. McCullon. *Rev. Sci. Instr.* **31**, No. 7, 780-781 (July, 1960).
- Casimir coefficients and minimum entropy production, R. E. Nettleton, *J. Chem. Phys.* **33**, No. 1, 237-241 (July, 1960).
- Variations of surface tension calculated with improved approximation for activity coefficient, L. C. Shepley and A. B. Bestul. *J. Am. Ceram. Soc.* **43**, No. 7, 386-387 (July, 1960).
- Council adopts F. D. I. specification for alloy for dental amalgam, Council on Dental Research, *J. Am. Dental Assoc.* **60**, No. 6, 773 (June, 1960).
- The foundations of mechanics and thermodynamics, E. A. Kearsley and M. S. Green, *Phys. Today* **13**, No. 7, 22-25 (July, 1960).
- Optical methods for negative ion studies, S. J. Smith and L. M. Branscomb, *Rev. Sci. Instr.* **31**, No. 7, 733-747 (July, 1960).
- On the theory of the slow-tail portion of atmospheric waveforms, J. R. Wait, *J. Geophys. Research* **65**, No. 7, 1939-1946 (July, 1960).
- Statistical aspects of the cement testing program, W. J. Yonden. *Am. Soc. Testing Materials Proc.* **59**, 1120-1128 (1959).
- Optical transmissivity and characteristic energy losses, H. Hendlowitz, *J. Opt. Soc. Am.* **50**, No. 7, 739-740 (July, 1960).
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- A barium fluoride film hygrometer element, F. E. Jones and A. Wexler, *J. Geophys. Research* **65**, No. 7, 2087-2095 (July, 1960).
- Low-energy photoproduction of neutral mesons from complex nuclei, R. A. Schrack, S. Penner, and J. E. Leiss, *Il Nuovo Cimento* **16**, Serie X, 759-761 (March, 1960).
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- Structure of sulfuric esters, H. Finegold, *Proc. Chem. Soc. (London)* 283-284 (August, 1960).
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